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The Use of Grassed Buffer Strips to Remove Pesticides, Nitrate and Soluble Phosphorus Compounds from Runoff Water*

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Abstract: Experiments on grassed buffer strips have been conducted since 1993 by ITCF (Institut Technique des Céréales et des Fourrages) at three research farms (La Jaillière, Bignan and Plélo). Literature data and conclusions drawn from previous work with isoproturon and diflufenican were confirmed in a range of soil and cropping conditions: grassed buffer strips are effective in restricting pollutant transfer in runoff; those with widths of 6, 12 and 18 m reduced runoff volume by 43 to 99·9%, suspended solids by 87 to 100%, lindane losses by 72 to 100% and loss of atrazine and its metabolites by 44 to 100%. More than 99% of isoproturon and 97% of diflufenican residues in runoff were removed by buffer strips. Nitrate and soluble phosphorus in runoff were reduced by 47 to 100% and by 22 to 89%, respectively. At La Jaillière, a rainfall simulator was used in 1995 to verify that buffer strips are still effective in conditions of intense runoff. Investigation of the influence of sowing direction during the 1994–95 cropping period at Bignan showed that sowing perpendicular to the slope seemed to be beneficial in reducing pesticide content in runoff.

Key words: grassed buffer strip, pesticide, runoff, water quality

1 INTRODUCTION

Pesticide losses from treated areas through runoff may cause surface water quality deterioration. In order to mitigate impacts of agricultural practices, conservation tillage systems and grassed buffer strips have been studied essentially in the USA. According to Baker *et al.*[1] who summarized historical data (1970–1990), all conservation tillage systems reduced herbicide runoff by an average 60%, when compared to mouldboard plowing. Historical data show that buffer strips increase water infiltration,[1–3] trap sediment[2–4] and reduce nutrients transport from feedlots.[5–10] Buffer strips studies have also shown reductions in herbicide transfer in runoff and results are summarized in Table 1.

In France, a series of studies have been conducted since 1992 by the Institut Technique des Céréales et des Fourrages (ITCF) to evaluate the effectiveness of grassed buffer strips in restricting pollutant transfer in runoff. The first, started in November 1992 at La Jaillière (Brittany) experimental farm (in collaboration with

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TABLE 1
Published Data on Reduction of Herbicide Loss Through Runoff in Fields with Grassed Buffer Strips

Date	*Herbicide*	*Reduction in runoff* (%)	*Workers*	*Reference*
1977	2,4 D	69–71	Asmussen *et al.*	15
1980	Trifluralin	86–96	Rohde *et al.*	16
1983	Atrazine	65–91	Hall *et al.*	1[a]
1993	Metolachlor	50–75	Webster *et al.*	1[a]
1993	Metribuzin	50–75	Webster *et al.*	1[a]
1995	Metolachlor	56	Murphy *et al.*	1[a]
1995	Metribuzin	56	Murphy *et al.*	1[a]
1995	Atrazine	30–57	Hoffman	1[a]
1995	Atrazine	44–50	Hoffman	1[a]
1993	Atrazine	35–59·5	Mickelson & Baker	1[a]
1994	Atrazine Metolachlor Cyanazine	[b]	Misra	1[a]
1992	Isoproturon Pendimethalin	[b]	Michenfelder & Schramm	19

[a] Reference 1 is a review which cites these references.
[b] Amount of reduction not quoted in the paper.

Cemagref and Rhône-Poulenc Agro), aimed at determining the efficacy of 5·7 (narrow) and 11·1 m (wide) grassed strips in reducing isoproturon and diflufenican transfer in runoff generated on small plots (125 m^2).[11] The results obtained during three successive cropping periods (1992–1995) showed that runoff volume was reduced by 8 to 89% in the narrow strip and by 37 to 91% in the wide strip. Suspended solids were retained by 69 to 90% and 69 to 97% in the narrow and wide strips, respectively. The same strips removed 75 to 97% and >97%, respectively, of isoproturon lost from the winter wheat plots in runoff; the corresponding figures for diflufenican were 68 to 90% and >96%. Very small amounts of isoproturon and diflufenican were lost in runoff solid phase and only traces were released out of the strips. The 5·7 and 11·1 m strips were responsible for the retention of >75% of isoproturon and >83% of diflufenican lost in runoff liquid phase. As suggested by Baker *et al.*,[1] sorption of herbicides onto organic matter and vegetation in the grassed buffer strip probably contributes significantly to the effectiveness of the filter strip.

Since 1993, additional experimental sites have been implemented at the La Jaillière, Bignan and Plélo ITCF research farms. The objective was to determine the effectiveness of grassed buffer strips in reducing pesticide losses in runoff from larger cultivated plots. A rainfall simulator was used (in collaboration with Cemagref) to evaluate the efficacy of grassed buffer strips in conditions of intense runoff. In addition, the influence of sowing direction on pollutant runoff losses was evaluated at Bignan during the 1994–95 cropping period. This paper presents results from these studies.

2 MATERIALS AND METHODS

2.1 Experimental sites

Studies were carried out from 1993 to 1995 at La Jaillière, Bignan and Plélo ITCF research farms located in Brittany (France). Experimental sites consisted of four cultivated plots (250 m^2) bordered with a plastic sheet. A 20-m wide grassed buffer strip (rye-grass sown perpendicularly to the slope) was installed at the lower edge of the plots. Runoff generated on each plot (Fig. 1; B0, B6, B12 and B18) was collected *via* a galvanized metal sheet and drained into a tank after filtration through 0, 6, 12 or 18 m of grassed strip (Fig. 1). The grassed buffer strips represented 12, 24 and 36%, respectively of the cultivated plot areas.

Characteristics of each site are summarized in Table 2. At La Jaillière, the soil is a hydromorphic silt loam containing 2% organic matter (OM) and Bignan and Plélo soils are silt loams with 7 and 3% OM, respectively.

At Bignan during the 1994–95 cropping period, the experimental site included eight winter wheat plots (250 m^2). Herbicides were applied on four plots before wheat tillering and on the others at wheat full tillering stage. For each application time, winter wheat was sown parallel to the slope in two plots (B0 and B12) and perpendicularly to the slope on the others.

A rainfall simulator was used in March 1995 at La Jaillière first experimental site. This site consisted of three winter wheat plots (125 m^2) and runoff generated on each plot (B0, B6 and B12) was collected after filtration through 0, 5·7 or 11·1 m of ryegrass strip.[11]

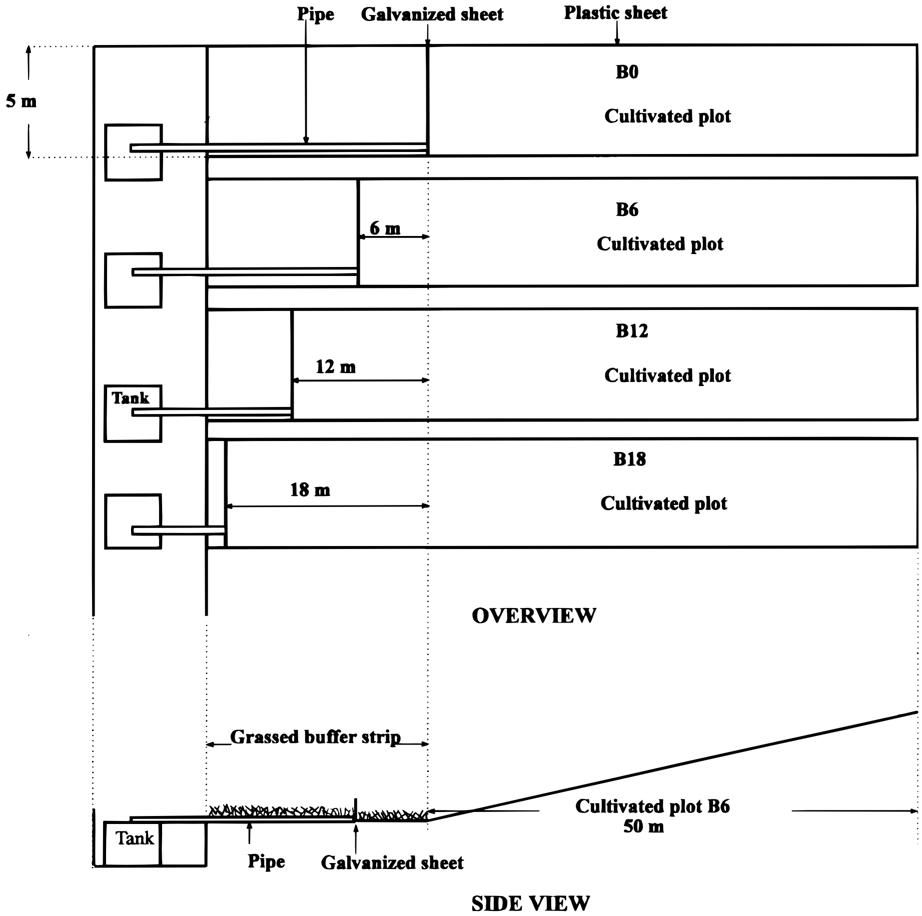

Fig. 1. Grassed buffer strip experimental site at La Jaillière, Bignan and Plélo farms.

TABLE 2
Characteristics of the Experimental Sites

	La Jaillière	*Bignan*	*Plélo*
Total rainfall per year (mm)	650	920	700
Soil type	Hydromorphic silt loam	Silt loam	Silt loam
Mean plot slope (%)	7	10	15
Soil preparation	Plowing	Plowing	Plowing
Cropping period	1993–94	1993–94 (1994–95)	1994–95
Crop	corn	Corn (winter wheat)	Winter wheat
Sowing direction	Parallel to the slope	Parallel to the slope (parallel and perpendicular to the slope)	Parallel to the slope
Rye grass age (years)	3·5	2·5	1·5
Strip width (m)	6, 12 and 18	6, 12 and 18 (12)	6, 12 and 18
Pesticides applied	Lindane, atrazine	Lindane, atrazine (isoproturon, diflufenican)	Isoproturon, Diflufenican
Soil Characteristics			
Clay (%)	20	16	12
Silt (%)	45	43	47
Sand (%)	33	34	38
Organic matter (%)	2	7	3

2.2 Pesticides applied

Pesticides with different environmental behaviour were selected (Table 3). Isoproturon, like atrazine, is relatively water-soluble and moderately adsorbed on soil. Diflufenican has a very low water solubility and is strongly adsorbed, like lindane which is slightly water-soluble. Thus, lindane and diflufenican on the one hand and isoproturon and atrazine on the other represent two groups of plant-protection products with different environmental behaviours.

Lindane was soil-incorporated in compliance with existing French regulations, whereas atrazine, isoproturon and diflufenican were broadcast sprayed. Products were applied as commercial suspension concentrates at registered rates: 1350 g ha^{-1} for lindane, 1250 g ha^{-1} for atrazine and isoproturon and 156 g ha^{-1} for diflufenican (Table 3).

2.3 Determination of runoff characteristics

Runoff volumes were measured in each tank after each rainfall event. The tank contents were homogenized and runoff water samples (1–2 litres) were taken from each tank and stored at -18°C. Residues in runoff water were analysed at the Coopagri Bretagne laboratory. Pesticide residues were extracted with dichloromethane and analysed by chromatography.[12] Lindane, diflufenican, atrazine and its metabolites were analysed by gas chromatography with a Hall detector: injector and detector temperatures were 280°C; the column was a 30 m × 0·30 mm ID semipolar (J&W, DB17) fused-silica capillary column coated with 17% phenylmethyl-polysiloxane; the oven temperature program was: initial temperature 90°C held for 1 min, 90 to 240°C at 20°C min^{-1}, 240 to 275°C at 10°C min^{-1}, held for 18 min; the carrier gas was helium. Isoproturon was analysed by high performance liquid chromatography with UV detection (λ: 245 nm): the isocratic chromatographic separation was achieved on a Nucleosil column (250 × 4 mm, silica-C18, 5 μm) using an acetonitrile + water mixture (60 + 40 by volume); the flow rate was 1 ml min^{-1} and the injection volume was 20 μl. Nitrate concentration in runoff was determined by ionic chromatography equipped with a conductimetric detector: flow rate 0·8 ml min^{-1}; IC pak anion HR HPLC column (4·6 × 75 mm) eluted with borate + gluconate mixture (280 μS). Soluble phosphorus concentration was determined by UV detection using the NF T90-023 standard method.

3 RESULTS AND DISCUSSION

3.1 Natural rainfall events

Intensity of rainfall events generating runoff ranged from 10·3 to 29 mm at La Jaillière (1993–94), 15·4 to 22·4 mm at Bignan (1993–94), 27 to 57 mm at Plélo (1994–95) and from 3·8 to 85 mm at Bignan during the 1994–95 cropping period (Fig. 2). Eight and 25 runoff events were collected at Plélo and Bignan, respectively, during the 1994–95 cropping period. Only three and five runoff events were collected at Bignan and La Jaillière, respectively, during the 1993–94 period. The three experimental sites thus provided a set of varying experimental conditions.

Because of limited capacity (250 litres), tanks overflowed at La Jaillière and Bignan during the 1993–94 cropping period after intense rainfall events.[13] For example, at Bignan, the first runoff event (28 May 1994) occurred after a total rainfall of 100 mm in the previous days. Despite increased tank capacity (640 litres in autumn, 1994), tanks overflowed occasionally during the 1994–95 cropping period at Bignan because of exceptional rainfalls. Therefore, caution should be exercised when considering, in certain events, total pesticide losses in runoff and GBS (grassed buffer strips) effectiveness because of the low accuracy in runoff determination.

TABLE 3
Physicochemical Properties of Applied Pesticides and Application Dates

	Isoproturon	*Diflufenican*	*Lindane*	*Atrazine*
Water solubility (mg litre^{-1})[a]	65	0·05	7	33
K_{oc} (cm^3 g^{-1})[a]	120	1990	1100	100
Half-life (days)[a]	12–32	175–294	100–120	60–70
La Jaillière (1993–94)			29 April 1994	29 April 1994 9 June 1994
Bignan (1993–94)			20 May 1994	25 May 1994
Bignan (1994–95[b])	23 Dec. 1994	23 Dec. 1994		
Bignan (1994–95[c])	21 Feb. 1995	21 Feb. 1995		
Plélo (1994–95)	3 Jan. 1995	3 Jan. 1995		

[a]: Data supplied by Rhône-Poulenc Agro.
[b]: Before wheat tillering.
[c]: At wheat full tillering stage (Zadoks 25).

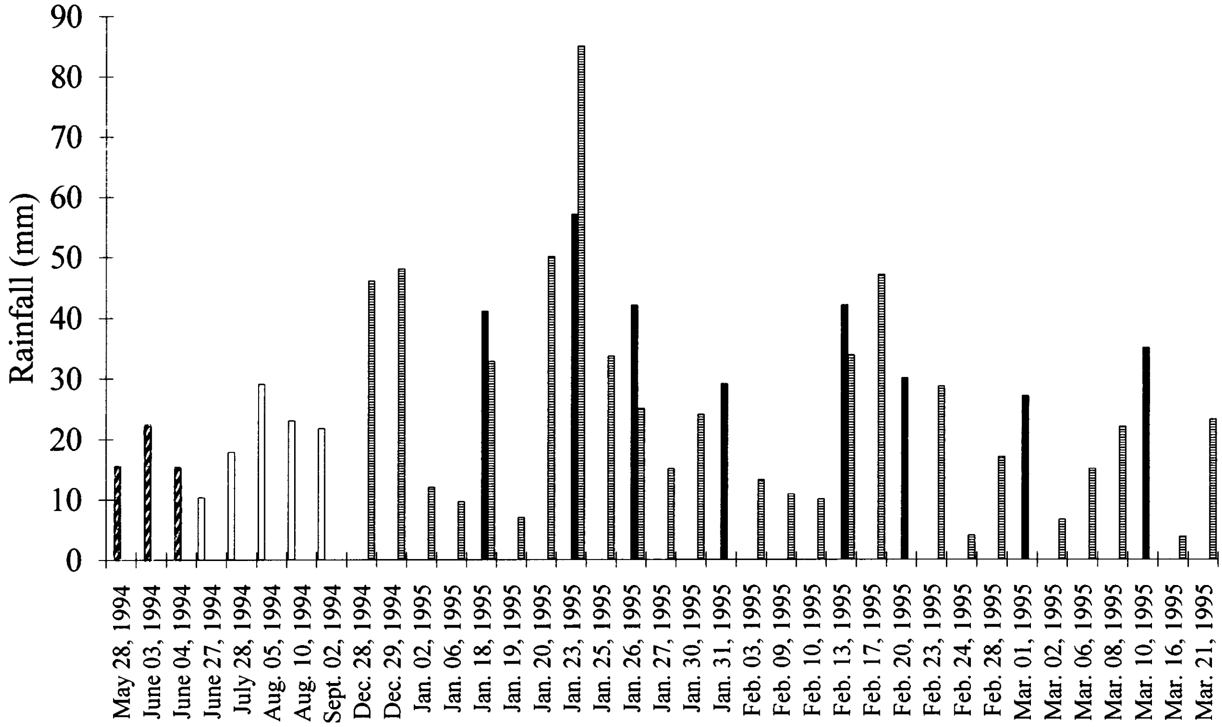

Fig. 2. Rainfall data (mm) for each runoff event collected after pesticide application. (□) La Jaillière 1993–94, (▨) Bignan 1993–94, (■) Plélo 1994–95, (▤) Bignan 1994–95.

3.2 Pesticide losses in runoff

Total pesticide losses in runoff were estimated using the results obtained for B0 plots. At Plélo experimental site (where the tank did not overflow) isoproturon and diflufenican losses in runoff represented 0·03 and 0·18% of the applied amounts, respectively (Table 4). The three runoff events which occurred immediately after application were responsible for the major losses (95% of total isoproturon and 87% of diflufenican). At Bignan, during the 1993–94 cropping period, 0·0006% of lindane and 0·63% of atrazine applied on corn plots were found in runoff. Pesticides lost in the two first events corresponded to 89 and 81% of total lindane and atrazine runoff losses. At La Jaillière (1993–94), lindane and atrazine runoff losses represented 0·0003 and 0·017% of pesticides applied. At Bignan during the 1994–95 cropping period not all samples were analysed, so total pesticide losses could not be determined.

TABLE 4
Pesticide Losses in Runoff (from B0 Plots) at Plélo, Bignan and La Jaillière

Total losses in runoff	*mg 250 m^{-2}*	*g ha^{-1}*	*% of applied*
Plélo (1994–95)			
Isoproturon	9·25	0·37	0·03
Diflufenican	6·97	0·28	0·18
Bignan (1993–94)			
Lindane[a]	0·20	0·008	0·0006
Atrazine	196·6	7·86	0·63
La Jaillière (1993–94)[b]			
Lindane	0·098	0·0039	0·0003
Atrazine	5·21	0·21	0·017

[a]: Runoff at 28 May 1994 not included.
[b]: Runoff at 10 August and 27 June 1994 not included.

In summary, less than 0·7% of pesticides applied moved from the plots in runoff and reached the grassed buffer strip, under the experimental conditions described. These results are consistent with those obtained in the first experimental site (started at La Jaillière in 1992)[11] and the conclusions reached by Wauchope.[14] Actually, Wauchope reported that, for the majority of pesticides, total losses were usually 0·5% or less of the amount applied unless runoff occurred shortly after herbicide application. In the latter situation, losses of 2 to 17% were reported. Our results show that the amounts of pesticide lost in runoff depend greatly on the time elapsed between application and the first rainfall event: the shorter the time between application and rainfall, the larger the residues in runoff. Therefore, the ability of grassed buffer strips to remove pesticide residues is best evaluated in the first events, when transfer probability is maximal.

3.3 Effectiveness of grassed buffer strips

3.3.1 Natural rainfall conditions

Figure 3 shows that isoproturon and diflufenican losses in the first runoff events (at Plélo 1994–95) were removed to a large extent in grassed buffer strips of

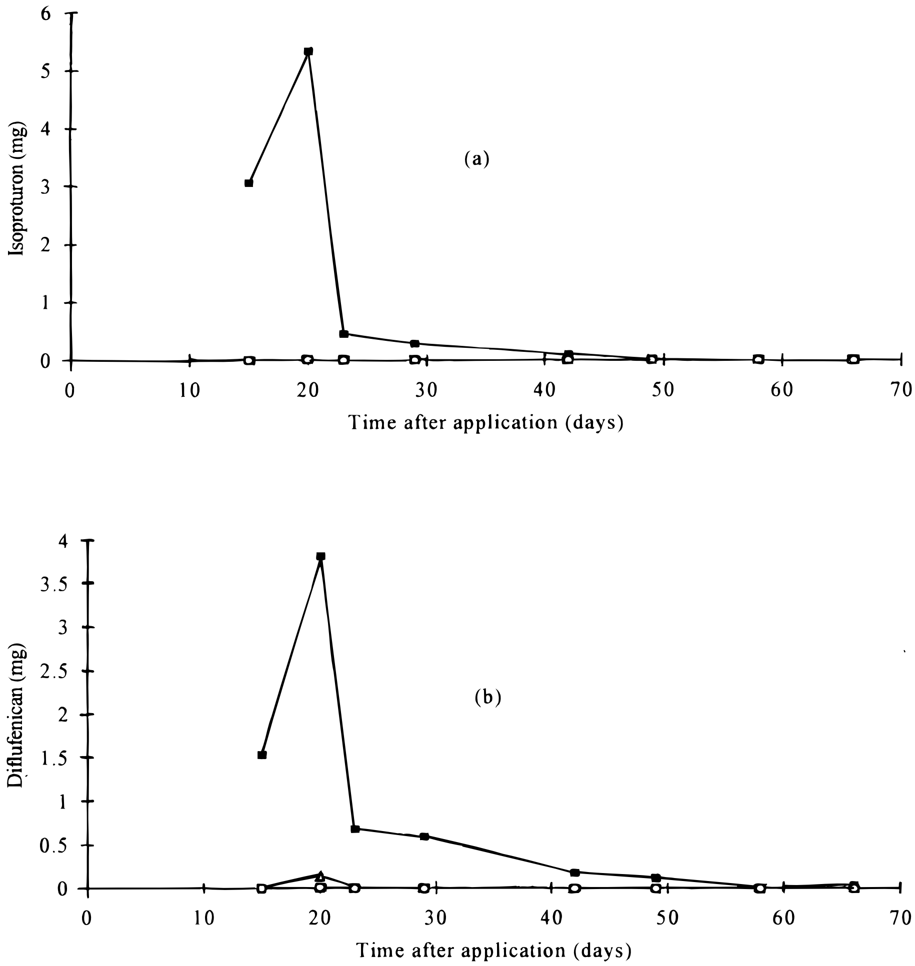

Fig. 3. Losses of (a) isoproturon and (b) diflufenican in runoff at Plélo (1994–95). (—■—) B0 (—△—) B6 (—×—) B12 (—○—) B18.

various widths thus confirming their efficacy in restricting pesticide transfer in the first runoff events following application. The results obtained at La Jaillière, Bignan and Plélo during the whole cropping periods are presented in Table 5.

Variations in runoff volume and residue concentration observed under different conditions on three experimental sites provide an overview of the effectiveness of grassed buffer strips. Runoff volume was reduced by 43 to 99·9% with the strips and 87 to 100% of suspended solids transported in runoff were retained. Lindane and atrazine runoff losses were reduced by 72 to 100% and by 44 to 100%, respectively, with the grassed buffer strips (La Jaillière and Bignan). Losses of atrazine metabolites in runoff were reduced by 45 to 100% in the same time. Finally, at Plélo grassed buffer strips removed >99% of isoproturon and >97% of the diflufenican lost from the plots in runoff.

When results obtained for each runoff event were averaged, lindane losses in runoff were reduced by 76, 99·8 and 100%, respectively, in 6-, 12- and 18-m-wide strips. The same strips removed 83, 91 and 99% of atrazine (La Jaillière and Bignan). At Plélo, isoproturon losses were reduced by 95, 99·9 and 100%, respectively, with the 6-, 12- and 18-m strips and 98·8, 99·9 and 100% of diflufenican in runoff was removed with the same strips.

Figure 4 shows that the effectiveness of grassed buffer strips seems to be independent of rainfall intensity. In various experimental conditions, buffer strips exhibited a relatively good efficacy level (>80%), lower results corresponding to very high runoff volumes (i.e. tank overflowings).

Results presented in this paper are in good agreement with literature data[1,15,16] and with those obtained in previous work with isoproturon and diflufenican.[11] Grassed buffer strips are effective in reducing runoff volume, trapping sediment and restricting pesticide transfer in runoff for strongly adsorbed pesticides (diflufenican and lindane) and relatively water-soluble pesticides (isoproturon and atrazine). Several hydrological as well as physicochemical processes are involved: infiltration of water and soluble pollutants within the strip; retention of sediment-bound pollutants due to filtration and sedimentation; retention of soluble pollutants by sorption onto organic matter and vegetation in the strip.[1,11] These processes are expected to be more effective in conditions of low runoff velocity.

TABLE 5
Total Pollutant Losses in Runoff at La Jaillière, Bignan and Plélo and the Effectiveness of Grassed Buffer Strips for the Whole Cropping Periods[a]

Experimental site	*Bignan 1993–94*				*La Jaillière 1993–94*[b]				*Plélo 1994–95*			
Plot	*B0*	*B6*	*B12*	*B18*	*B0*	*B6*	*B12*	*B18*	*B0*	*B6*	*B12*	*B18*
Strip width (m)	*0*	*6*	*12*	*18*	*0*	*6*	*12*	*18*	*0*	*6*	*12*	*18*
Runoff volume (litre)	480	275 (43)	220 (54)	30 (94)	457	73 (84)	12·4 (97)	0·3 (99·9)	535·3	71·1 (87)	38·85 (93)	80 (85)
Sediment (mg)	20·40[c]	2·53[c] (87)	0[c] (100)	0[c] (100)	493·2	5·44 (98·9)	3·70 (99)	0·37 (99·9)	309·16	28·71 (91)	8·21 (97)	4·8 (98)
Lindane (mg)	0·20[c]	0·055[c] (72)	0[c] (100)	0[c] (100)	0·098	0·007 (93)	0·0006 (99)	0 (100)	—	—	—	—
Atrazine (mg)	196·6	110·64 (44)	77·55 (60)	6·06 (97)	5·21	0·173 (97)	0·0078 (99·8)	0 (100)	—	—	—	—
Deethylatrazine (mg)	4·96	2·25 (55)	1·25 (75)	0·096 (98)	1·15	0·061 (95)	0·0028 (99·7)	0 (100)	—	—	—	—
Deisopropylatrazine (mg)	5·828	3·18 (45)	1·89 (67)	0·14 (97)	0·647	0·025 (96)	0·0012 (99·8)	0 (100)	—	—	—	—
Isoproturon (mg)	—	—	—	—	—	—	—	—	9·25	0·023 (99·7)	0·010 (99·9)	0·008 (99·9)
Diflufenican (mg)	—	—	—	—	—	—	—	—	6·97	0·18 (97·4)	0·011 (99·8)	0·008 (99·9)
Nitrate (mg)	2958	1562 (47)	924 (69)	33 (99)	2460·2	376·8 (85)	61·68 (97)	0·03 (100)	2576·5	364·1 (86)	138·9 (95)	88 (97)
Soluble P (mg)	28·4	16·5 (42)	22 (22)	3 (89)	48·9	69·1 (0)	26·44 (46)	8·28 (83)	263·7	55·8 (79)	27·9 (89)	28·8 (89)

[a] Effectiveness, in parentheses, expressed as the ratio between results for a given strip and those for the corresponding B0 plot.
[b] Runoff at 10 Aug. and 27 June 1994 not included.
[c] Runoff at 28 May 1994 not included.
— Herbicide not applied.

3.3.2 Simulated rainfall conditions
In order to determine the efficacy of grassed buffer strips in conditions of intense runoff, a rainfall simulator was used in March 1995 at La Jaillière (first site). Simulated rainfall was generated 14 days after isoproturon and diflufenican application and one day after a natural rainfall of 24·3 mm. Because of a lateral wind, simulated rainfall received by winter wheat plots varied from 9·5 mm (B0 in 30 min) to 25 mm (B6 and B12 in 51 min). The effectiveness of 6- and 12-m strips was

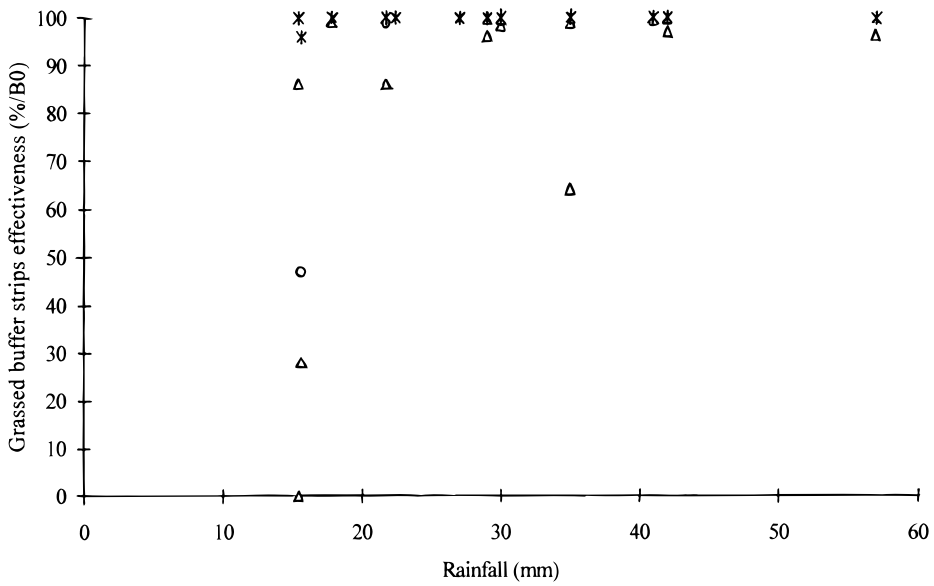

Fig. 4. Variations of grassed buffer strips' effectiveness for all pesticides at the three experimental sites. (△) B6(○) B12(✳) B18.

therefore under-estimated. Nevertheless, buffer strips still exhibited a significant capacity to reduce pollutant transport in runoff. In the experimental conditions described, soil was already crusted before rain simulation started. Isoproturon and diflufenican concentrations in raw runoff were reduced by an average of 58% with a 5·7-m strip and by 68% with a 11·1-m strip. Isoproturon and diflufenican concentrations in runoff liquid phase were reduced by 55 and 75% with the narrow strip and by 61 and 73% with the wide strip. Isoproturon concentration in solid phase was lowered by 51 and 76%. In this experiment, runoff samples were collected during rainfall simulation and solid particle loads and isoproturon and diflufenican concentrations in runoff were determined. Suspended solids rate decreased with time (Fig. 5), thus supporting previous conclusions of Munoz[17] and Gouy[18]: the stock of particles available for runoff on the surface of the plot is progressively depleted. The two runoff events which occurred between pesticide application and rainfall simulation may be responsible for the low variations observed in isoproturon and diflufenican concentration in runoff, compared to those obtained by Gouy.[18] In spite of this, as shown by Gouy[18] for various pesticides, diflufenican concentration in runoff seemed to decrease with time (Fig. 5), as if the stock of herbicide in soil available for runoff was progressively depleted. The increased concentration observed with isoproturon is unexplained for the moment and probably represent fluctuations in a low concentration range. This assumption, based on preliminary observations, should be verified with additional results generated by extra rainfall simulation carried out in 1996.

3.4 Influence of sowing direction

At Bignan during the 1994–95 cropping period, nine and four runoff samples taken at two application times, before wheat tillering (BT) and at wheat full tillering stage (FT), respectively, were analysed. Preliminary results showed that, when wheat sown perpendicularly to the slope was compared with wheat sown parallel to the slope, runoff suspended solids were reduced by an average 58% before the runoff reached the strip (BT).

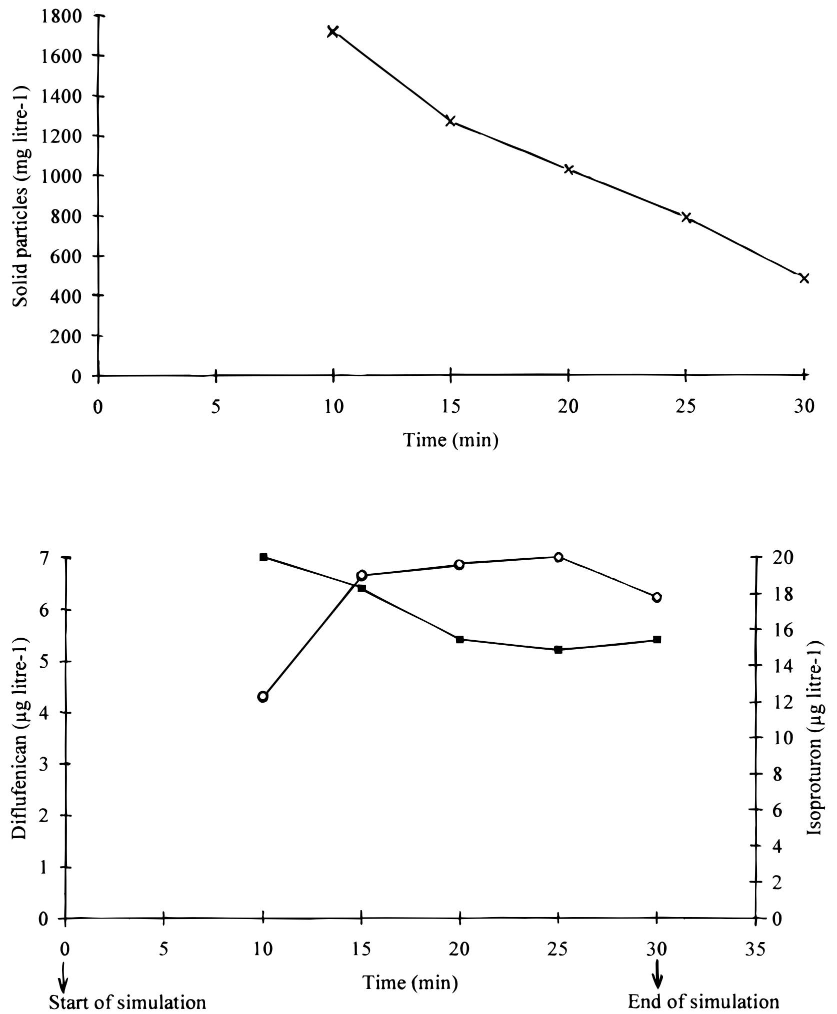

Fig. 5. Analytical results for runoff collected (from B0 plot) during the 1995 rainfall simulation. (—■—) diflufenican (—○—) isoproturon.

Isoproturon losses in runoff were reduced by 23% (BT) and 44% (FT) and diflufenican losses by 36% (BT) and 7% (FT). Values between application times cannot be compared validly since not all runoff samples were analysed. In spite of this, a sowing direction perpendicular to the slope seems to be beneficial in reducing pollutant transfer in runoff before and reaching the grassed buffer strip. This observation should be verified and more information provided with additional results obtained during the 1995–96 cropping period.

4 CONCLUSIONS

Studies conducted by ITCF since 1993, at La Jaillière, Bignan and Plélo research farms, have proved that grassed buffer strips are effective in reducing pesticide losses in runoff during the whole cropping period and under various experimental conditions. In agreement with the literature,[5–10] our results showed that nitrate and soluble phosphorus losses in runoff were also reduced significantly by 47 to 100% and by 22 to 89% with the strips. In spite of experimental limitations, rainfall simulation results indicated that the strips are still effective in conditions of intense runoff. Grassed buffer strips provide a way to improve surface water quality in agricultural areas. The experiments are continuing in the 1996 cropping period with rainfall simulation used to confirm the results with another set of data.

Grassed buffer strip implementation should be considered in the context of water quality management. At the moment, ITCF, in collaboration with Cemagref, Rhône-Poulenc Agro and the French Ministry of Agriculture is working on strategies of grassed buffer strip implementation in the watershed so as to develop a workable tool to reduce agricultural non-point source pollution of surface water. Following promising results at field level, grassed buffer strip effectiveness should now be assessed at the scale of an entire watershed.

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